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Public Food Security and Logistic Challenges in ASEAN: Prioritising Supply Chain Risks in the Nutritious Meal Programme of Indonesia's Outer Islands

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ABSTRACT

Ensuring equitable food distribution across geographically dispersed archipelagic regions remains a critical challenge for public food security programmes in ASEAN. Indonesia's Free Nutritious Meal Programme (Program Makan Bergizi Gratis/MBG) faces significant logistical constraints in its outermost (3T) regions, where fragmented transportation networks, limited cold-chain infrastructure, and heavy dependence on external suppliers reduce supply chain reliability. Although previous studies have applied the Supply Chain Operations Reference (SCOR) model or the House of Risk (HOR) framework independently, limited research has integrated the ***Supply Chain Operations Reference Digital Standard (SCOR-DS)*** *and HOR to simultaneously evaluate supply chain performance and prioritize operational risks in public food distribution systems. This study proposes an integrated SCOR-DS–HOR framework to evaluate supply chain performance, identify critical risk agents, and determine priority mitigation strategies for the MBG programme. Data were collected from 54 stakeholders representing suppliers, logistics providers, programme administrators, and government agencies through structured questionnaires and semi-structured interviews. Supply chain performance was assessed using SCOR-DS Level 1 metrics, while HOR Phases I and II were employed to prioritize risk agents and evaluate mitigation alternatives using the Effectiveness-to-Cost Ratio (ETCR). The findings indicate that the MBG supply chain operates at a vulnerable level, with a Perfect Order Fulfilment (POF) score of* ***75.4%****. The most critical risk agents are inadequate cold-chain infrastructure, dependence on external suppliers, and maritime transportation disruptions, accounting for more than 60% of total operational risk. The most cost-effective mitigation strategies include improving pre-cooling procedures, strengthening partnerships with local suppliers, and increasing emergency safety stock. This study contributes an integrated decision-support framework that links supply chain performance evaluation with risk prioritization to strengthen public food logistics resilience in Indonesia's outer islands and other*

1. Introduction*

Food security has become one of the world's most pressing sustainable development challenges due to population growth, climate change, geopolitical instability, and increasing supply chain disruptions. Ensuring equitable access to safe, nutritious, and affordable food is explicitly emphasized in Sustainable Development Goal (SDG) 2 (Zero Hunger) and SDG 3 (Good Health and Well-being). However, achieving these goals requires not only sufficient food production but also resilient and efficient supply chain systems capable of delivering food to vulnerable populations in a timely and reliable manner. According to [1] global food security is further complicated by population growth, poverty, and environmental sustainability. Over 345 million people are hungry, and 2 billion lack essential micronutrients. Climate change and other global crises aggravate these issues. To achieve global food security, there is a need to transform into governance-oriented, resource-efficient, and resilient food systems that align with the Sustainable Development Goals (Varzakas & Smaoui, 2024).

Within ASEAN, food security presents unique logistical challenges because archipelagic geography, fragmented transportation networks, and uneven infrastructure development characterize several member states. Reliable food distribution is therefore essential to ensure equitable access to nutritious food, particularly for populations living in remote and island regions. Indonesia, as the world's largest archipelagic country with more than 17,000 islands, represents one of the most challenging logistics environments in ASEAN. Long transportation distances, high distribution costs, dependence on maritime transport, and uncertain delivery schedules significantly increase supply chain complexity and reduce distribution reliability (Sundram, 2023).To improve national nutritional status and support the vision of Golden Indonesia 2045, the Government of Indonesia launched the Free Nutritious Meal Programme (Program Makan Bergizi Gratis—MBG). The programme aims to provide nutritious meals to school-aged children and other vulnerable populations through a nationwide food distribution network. While the programme offers significant social and public health benefits, its successful implementation depends heavily on the reliability and resilience of the underlying supply chain. This challenge is particularly evident in Indonesia's outermost (3T) regions, where limited infrastructure, dependence on maritime transportation, and weather-related disruptions frequently hinder food distribution.

The supply chain infrastructure is not good enough, depends on shipping, and is affected by bad weather, which makes supply chain problems worse. So, for government programs to work, they need to have a systematic and structured understanding of the supply chain and the risks that come with it, not just focus on nutrition policy and outcomes.

Public food supply chains differ substantially from commercial supply chains because they involve perishable products, multiple stakeholders, strict service requirements, and high uncertainty associated with transportation and storage. These characteristics increase operational complexity and require systematic performance evaluation together with proactive risk management to ensure reliable food distribution, particularly in geographically dispersed regions.[4]. The food industry has major environmental, economic, social, and political concerns. The public is increasingly concerned with food safety, production practices, environmental issues like deforestation, climate change, and energy use, as well as social concerns like fair salaries and population increase[5][6].

Other challenges involve assessing the impacts of the supply chain, collaboration and networks, stakeholder involvement, and the achievement of sustainable development goals. These challenges reinforce the understanding that food supply chains differ due to the unique risk and uncertainty characteristics associated with perishability, production seasonality, and the conditions of storage and transportation. Ensuring the safety of food has always been the main focus of state and public authorities, the food industry, and scholars. However, emerging challenges may, among other things, arise from the intricately growing food supply, rapid food supply chain climate changes, the increasing global trade of food, new food sources and technologies, and concepts of the circular economy and urban food production. Appropriate tools and methods for early warning and the identification of emerging risks form a solid basis for building food systems resilient to threats to food safety, prioritized by national and international food safety authorities and organizations, and improving their capacity for prevention, mitigation, and response to emerging food risks (FAO(2024) [7].

Supply chain performance can be systematically evaluated using the Supply Chain Operations Reference (SCOR) model, which provides standardized performance metrics covering planning, sourcing, production, delivery, and return processes. In parallel, the House of Risk (HOR) framework has been widely adopted to identify critical supply chain risk agents and prioritize mitigation strategies. While SCOR focuses on operational performance measurement, HOR emphasizes proactive risk management. Integrating these complementary approaches provides opportunities to develop a more comprehensive decision-support framework for complex public food distribution systems.[8].

Despite the growing body of literature on supply chain performance measurement and supply chain risk management, several important research gaps remain. Although previous studies have successfully applied SCOR for performance evaluation and HOR for supply chain risk management, these approaches are generally implemented independently. Consequently, decision-makers often obtain performance indicators without understanding the operational risks that influence them, or identify critical risks without evaluating their impact on overall supply chain performance. Moreover, existing studies predominantly focus on manufacturing and commercial supply chains, while public-sector food distribution systems remain relatively underexplored. Empirical evidence from geographically dispersed archipelagic regions is also limited. These gaps highlight the need for an integrated framework capable of simultaneously evaluating supply chain performance and prioritizing operational risk mitigation in public food logistics.

Therefore, this study aims to develop an integrated framework combining the Supply Chain Operations Reference Digital Standard (SCOR-DS) and the House of Risk (HOR) to evaluate supply chain performance, identify critical risk agents, and prioritize mitigation strategies for the Free Nutritious Meal Programme (MBG) in Indonesia's geographically dispersed regions. Specifically, this study addresses three research questions concerning supply chain performance evaluation, risk identification, and mitigation prioritization.

This study contributes to the existing literature by proposing an integrated SCOR-DS–HOR framework that simultaneously evaluates operational performance and prioritizes supply chain risks. By combining these complementary approaches, the proposed framework enables performance diagnosis and proactive risk mitigation within a single analytical process, thereby providing a more comprehensive decision-support mechanism than the application of either method independently. Furthermore, the framework is applied to Indonesia's Free Nutritious Meal Programme (MBG), representing a public-sector food distribution system operating in geographically dispersed archipelagic regions. The incorporation of the Effectiveness-to-Cost Ratio (ETCR) further supports the prioritization of mitigation strategies based on both effectiveness and implementation cost.

From a theoretical perspective, this study extends the application of SCOR-DS by integrating it with the House of Risk framework, thereby linking supply chain performance evaluation with proactive risk management in public food logistics. From a practical perspective, the proposed framework provides policymakers and programme managers with evidence-based recommendations to strengthen the resilience of food distribution systems, particularly in geographically dispersed and logistics-intensive regions. The framework may also serve as a reference for other archipelagic countries facing similar public food distribution challenges.

2. Literature Review

The successful implementation of Indonesia's Free Nutritious Meal Programme (Program Makan Bergizi Gratis—MBG) depends not only on food availability but also on the effectiveness, resilience, and sustainability of its supply chain. As a nationwide public food distribution programme operating across geographically dispersed regions, MBG faces significant logistical challenges related to procurement, transportation, storage, and distribution. Consequently, understanding supply chain risks and evaluating operational performance are essential for ensuring programme effectiveness. This literature review synthesizes previous studies on supply chain risk management, supply chain performance measurement, the Supply Chain Operations Reference Digital Standard (SCOR-DS), and the House of Risk (HOR) framework to establish the theoretical foundation for the proposed integrated framework.

2.1. Supply Chain Risk Management (SCRM)

Deviyanti et al. [9] Supply Chain Risk Management (SCRM) refers to the systematic process of identifying, assessing, and mitigating risks that may disrupt the flow of materials, information, and financial resources throughout the supply chain. Effective SCRM enhances operational resilience, improves decision-making, and minimizes the impact of unexpected disruptions on organizational performance. Within public food distribution systems, proactive risk management is particularly important because food products are perishable and highly sensitive to transportation delays, storage conditions, and infrastructure limitations. Previous studies have demonstrated the successful application of SCRM across various industrial sectors. For example, Asrory [10] integrated the Supply Chain Operations Reference (SCOR) model and the House of Risk (HOR) framework to identify priority risk agents and formulate mitigation strategies in the energy sector. Their findings indicate that combining performance evaluation with proactive risk mitigation provides more effective managerial recommendations than applying each approach independently. These findings provide a useful methodological basis for extending the SCOR–HOR integration to public food distribution programmes such as MBG [10]

Food distribution programmes are exposed to multiple sources of uncertainty arising from transportation, storage, demand fluctuations, and product perishability. These characteristics make public food supply chains substantially more complex than conventional commercial supply chains. Previous studies have proposed various approaches for identifying and assessing food distribution risks .For instanceSingh [11] employed the Analytic Hierarchy Process (AHP) to develop a structured framework for evaluating distribution risks, whereas Artoonian et al. [12] utilized Failure Mode and Effects Analysis (FMEA) to assess perceived risks within regional food hub supply chains. Although these approaches effectively identify potential disruptions, they primarily focus on risk assessment and provide limited support for linking operational performance evaluation with mitigation prioritization. Consequently, an integrated approach remains necessary to strengthen the resilience of public food distribution systems.

2.2 Supply Chain Performance

Supply chain performance (SCP) reflects the ability of a supply chain to efficiently and effectively manage the flow of materials, information, and financial resources in achieving organizational objectives. Performance evaluation plays a critical role in identifying operational inefficiencies, improving resource utilization, and enhancing supply chain resilience, particularly in public food distribution systems where service reliability and product quality are essential.Previous studies have identified several organizational and operational factors influencing supply chain performance. For example,Alsmairat et al. [13] demonstrated that organizational culture and supply chain innovation have significant positive effects on SCP, while supply chain relationships contribute indirectly through supply chain integration. These findings indicate that supply chain performance depends not only on operational processes but also on organizational capabilities and collaboration among supply chain partners. Within food supply chains, maintaining operational performance is particularly challenging because of product perishability, seasonal production, and the risk of food loss and waste. Studies conducted by Tannady et al. [14] and Oubrahim et al. [15] highlighted the importance of integrating qualitative and quantitative performance evaluation methods to improve decision-making in agricultural supply chains. Their findings showed that the implementation of the SCOR model up to Level 3 enabled comprehensive performance assessment across procurement, production, and distribution activities. The studies also identified procurement and production as the weakest processes, mainly due to weak supplier relationships, limited collaborative planning, forecasting and replenishment (CPFR), and ineffective inventory management. Recent studies have further emphasized the importance of digital technologies in improving supply chain performance. According to Hashmi[16], Artificial Intelligence (AI), adaptive capability, and supply chain collaboration significantly enhance supply chain resilience, which subsequently improves overall supply chain performance. These findings demonstrate that resilient supply chains require not only performance measurement but also adaptive capabilities supported by digital technologies and collaborative decision-making.

Although previous studies have successfully identified various determinants of supply chain performance, most research has focused on manufacturing, agriculture, and commercial supply chains. Comparatively limited attention has been devoted to public food distribution programmes operating in geographically dispersed archipelagic regions. Furthermore, existing studies generally evaluate operational performance without explicitly integrating performance assessment with systematic supply chain risk prioritization. This limitation highlights the need for an integrated framework capable of simultaneously evaluating supply chain performance and supporting proactive risk mitigation, which forms the basis for adopting the SCOR Digital Standard (SCOR-DS) and the House of Risk (HOR) framework in the present study.

2.3 Supply Chain Operations Reference Digital (SCOR Digital)

After the merger of the Supply Chain Council and APICS in 2014, ASCM created the Supply Chain Operations Reference Digital Standard (SCOR DS). Since its inception in 1996, the SCOR model has undergone periodic revisions to account for supply chain business practice changes. It continues to be a benchmarking standard for assessing and comparing supply chains. SCOR embodies the foundational perspective of supply chain management, offering the distinctive and integrative configuration that unites business processes, metrics, best practices, and technologies to foster enhanced communication among supply chain members and facilitate the effectiveness of supply chain management and its improvement Glencross and Chandra [17].

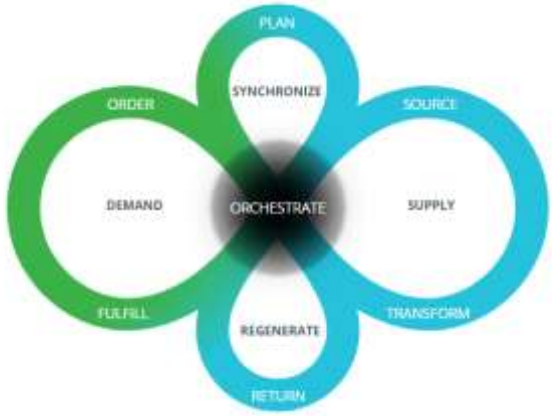

Fig. 1. SCOR-DS is organized around seven major management processes.

The graphic illustrating the SCOR-DS model is a double infinity diagram, representing today's supply chain's looped, continuous, and connected nature and the seven critical processes within every supply chain. The SCOR-DS graphic displays the balance of Supply and Demand in a horizontal infinity loop and Synchronize and Regenerate in a vertical infinity loop. SCOR spans all customer interactions from order entry through paid invoice; all physical material transactions that occur from the supplier's supplier to the customer's customer, including transactions for equipment, supplies, spare parts, bulk products, and software; and all market interactions from the understanding of aggregate demand to the fulfillment of each order. It does not attempt to describe every business process or activity. Specifically, SCOR does not address sales and marketing, including demand generation; product development; or research and development.

2.4 Relevance of the SCOR Digital Standard (SCOR-DS)

SCOR DS is a new evolution of the old framework, SCOR, which is globally recognized. SCOR DS was developed by ASCM. The SCORDS reference model it self is more comprehensive than before, with 6 categories integrated with the main processes **Plan, Order, Source, Transform, Fulfill, and Return** (Adwiyah et al., 2024). The SCOR-DS paradigm can change to fit the digital age by focusing on orchestration within a network, data integration, sustainability, and resilience indicators that are in line with Industry 4.0 SCM. SCOR-DS includes qualities that are useful for public logistics systems that will work in more complicated and spread-out areas, including Indonesia's outlying islands.SCOR-DS can improve overall visibility, starting from the physical flow and also the information flow. The Standard Metric Model in SCOR DS has 3 levels. Level 1 is strategic, Level 2 focuses on process categories, and

Level 3 consists of structured activities Adwiyah et al. [18]. The assessment of these dimensions of food distribution vertically integrated by Government agencies (National Government Agency, State government, Local Government) through separate or coordinated networked relationships across large distances) are very important for understanding potential logistical redundancies placed by the network participants. Numerous studies have documented the use of the SCOR-DS framework in studies of counterpart supply chains in a variety of fields. Notably, Ouyang and Huang [19] mention that since 2020 the digital SCOR model has emphasized eco-friendliness. Another example is Naziro [20], where the SCOR-DS model was also used in conjunction with the Analytic Network Process (ANP) in evaluating waste management performance. In the same vein, Apriyadi et al [21] explain the enhancement of the supply chain control of the SCOR Digital Standard method in the Cijurey Dam Project Package 1. The approach used is a mixed-methods approach with quantitative analysis to measure supply chain performance.

Considering that the MBG program in Indonesia is logistically very complex and there are many uncertainties in the process, SCOR-DS can help analyze and map critical supply chains, define measurable Key Performance Indicators (KPIs), and identify inefficiencies in procurement, storage, and distribution processes, particularly in island regions. The scalability of this model is also expected to integrate with the House of Risk (HOR) risk prioritization framework, which will systematically link performance results with the risks faced. This research seeks to establish evidence-based supply chain risk priorities in Indonesia's outermost island food program by utilizing the SCOR-DS framework in conjunction with HOR, thereby contributing methodologically and contextually to the discourse on food security logistics within the ASEAN region.

2.5 House Of Risk (HOR)

House of Risk (HOR) is a risk analysis technique based on the idea that preventive actions, or actions taken to reduce risk agents, should always be the primary focus of an active supply chain risk management program. HOR Phase 1: Identifying risk events and risk agents within the supply chain process based on mapping and taking actions to prevent the formation of natural risk agents to stop additional risk events from occurring. Aggregate Risk Priority (ARP) is the value used to determine the main priority. This study identifies potential disasters in Wonogiri Regency, including floods, landslides, and others, and provides recommendations for mitigation strategies using the House of Risk method, focusing on collaboration, education, resilient villages, mapping, and volunteer training for effective disaster management from 2021 to 2026 Setiawan and Pramana [22] This investigation utilizes the House of Risk (HOR) methodology to identify and mitigate risks associated with the Pak Chong GI durian cultivation and formulate recommendations on quality and sustainable approaches with respect to pest and disease control and climate change Jittamai et al. [23].

In the MBG Program, where food delivery will involve very complex inter-island logistics, weather uncertainty, and a weak supply chain infrastructure. HOR will help create a more systematic method for identifying and prioritizing the most critical and crucial risk agents that influence the success of a program. The results obtained using HOR can be strategic mitigation recommendations that will be targeted for regional storage center development, increasing supplier diversification, and implementing a more adaptive delivery scheduling system, which is expected to improve operational efficiency and overall public food security in Indonesia. Therefore, the use of the HOR framework in this study not only provides depth to the analysis but also offers insights for policy design in optimizing logistics within the broader ASEAN food security initiative.

2.6 Application of SCOR and HOR in Public Sector Programs

Fitriani and Nugraha [24] apply SCOR and HOR methods to identify and mitigate risks in the supply chain of a fish cracker company, but do not address public sector programs and The study suggests further research to quantify the impact of the proposed risk mitigation strategies and to consider additional variables in the review of risk events, risk agents, and preventive measures.

This research[10] provides an explanation regarding the formulation of risk mitigation recommendations based on the SCOR and HOR methods conducted in phases 1 & 2 in the energy context. Building on the proactive approach to risk management defined in the research, risks were not limited to events only, but also to risk agents, which led to the crafting of mitigation plans through the Effectiveness to Difficulty Ratio (ETD). Following the SCOR process (Plan, Source, Make, Deliver, Return), this research successfully defined 24 risk events and 30 risk agents mapped to the respective supply chain activities.

3 Research Method

3.1 Research Design

This study employed a mixed-methods case study approach integrating the Supply Chain Operations Reference Digital Standard (SCOR-DS) and the House of Risk (HOR) framework to evaluate supply chain performance and prioritize operational risks within Indonesia's Free Nutritious Meal Programme (Program Makan Bergizi Gratis—MBG) in the 3T (Underdeveloped, Frontier, and Outermost) regions. A mixed-methods approach was selected because it enables the integration of quantitative performance measurement with qualitative expert judgement, thereby providing a comprehensive assessment of both operational efficiency and supply chain resilience. Within the proposed framework, SCOR-DS was employed to map supply chain processes and evaluate operational performance using standardized supply chain metrics. Subsequently, the HOR framework was applied to identify critical risk events, determine priority risk agents, and formulate appropriate mitigation strategies. The integration of SCOR-DS and HOR enables performance evaluation and proactive risk management to be conducted within a unified analytical framework, providing more comprehensive decision support than applying either method independently. https://doi.org/10.5281/zenodo.17547732

3.2 Research Location and Participants

This study was conducted in one of Indonesia's 3T (Underdeveloped, Frontier, and Outermost) regions, which represents one of the country's most challenging public logistics environments. The selected study area is characterized by dispersed island geography, limited transportation infrastructure, dependence on maritime logistics, and frequent weather-related disruptions. These characteristics make the region an appropriate case for evaluating supply chain performance and risk management within the MBG programme.A purposive sampling technique was employed to select 54 respondents representing the principal stakeholders involved in the MBG supply chain. The respondents consisted of local food suppliers and distributors, maritime and land transportation providers, school meal coordinators, programme administrators, and officials from regional education and nutrition offices. This stakeholder composition ensured comprehensive representation of both operational and managerial perspectives throughout the supply chain.

Primary data were collected using two complementary methods. First, structured questionnaires were administered to evaluate SCOR-DS performance indicators and identify supply chain risk events and risk agents based on the HOR framework. Second, semi-structured interviews were conducted to obtain in-depth information regarding operational challenges, logistics constraints, and existing risk mitigation practices. Data collection was undertaken between March and June 2024 following approval from the relevant institutional authorities. All participants provided informed consent before participation, and confidentiality of the collected information was maintained throughout the research process.

3.3 Techniques for Data Analysis

The data analysis consisted of three sequential phases integrating SCOR-DS and the House of Risk (HOR) framework, as illustrated in Figure 2.

Fig. 2. Data analysis process

Phase 1: Supply Chain Mapping and Performance Evaluation. The MBG supply chain was first mapped using the SCOR Digital Standard (SCOR-DS) Level 3 process model, specifically the S2.1 Procure Stocked Product process. Operational performance was subsequently evaluated using Level 1 performance metrics, including Perfect Order Fulfilment (POF), Order Fulfilment Cycle Time (OFCT), and Total Supply Chain Management Cost (TSCMC). The performance evaluation served as the basis for identifying operational processes requiring further risk analysis.

Phase 2: Risk Identification and Prioritization. Potential risk events (Si) were identified from the SCOR-DS process mapping. Subsequently, expert respondents identified the corresponding risk agents (Aj), considering the specific logistics characteristics of the 3T regions, including maritime transportation delays, infrastructure limitations, and supplier dependency. The Aggregate Risk Priority (ARP) value was then calculated using the House of Risk Phase I methodology to determine the most critical risk agents requiring mitigation.

Phase 3: Mitigation Strategy Development. The final phase employed House of Risk Phase II to determine appropriate preventive actions for the priority risk agents identified in Phase I. Mitigation alternatives were evaluated using the Effectiveness-to-Cost Ratio (ETCR), enabling the selection of mitigation strategies that provide the greatest operational benefits while maintaining implementation feasibility within geographically dispersed public food distribution systems.

3.4 Research Framework

To ensure a systematic and comprehensive analysis, this study adopts an integrated research framework combining the Supply Chain Operations Reference Digital Standard (SCOR-DS) and the House of Risk (HOR) methodology. The framework was developed to evaluate both operational performance and supply chain risks within the Free Nutritious Meal Programme (Program Makan Bergizi Gratis—MBG) implemented in Indonesia's 3T (Underdeveloped, Frontier, and Outermost) regions.

The research framework consists of five sequential stages. The first stage involves identifying the research problem through literature review, field observations, and stakeholder interviews to understand the operational characteristics and logistical challenges of the MBG supply chain. The second stage focuses on mapping the supply chain processes using the SCOR Digital Standard (SCOR-DS) Level 3 process model, followed by performance evaluation using Level 1 performance metrics, including Perfect Order Fulfilment (POF), Order Fulfilment Cycle Time (OFCT), and Total Supply Chain Management Cost (TSCMC).

Based on the SCOR-DS mapping results, the third stage identifies potential supply chain risk events (Si) occurring throughout the procurement, transportation, storage, and distribution processes. Expert respondents subsequently identify the corresponding risk agents (Aj) that may trigger each risk event.

The fourth stage applies the House of Risk (HOR) methodology. HOR Phase I is employed to calculate the Aggregate Risk Priority (ARP) values and determine the most critical risk agents. Subsequently, HOR Phase II evaluates alternative preventive actions using the Effectiveness-to-Total Cost Ratio (ETCR), enabling the prioritization of mitigation strategies that provide the highest effectiveness with reasonable implementation costs.

Finally, the fifth stage formulates managerial recommendations based on the integration of operational performance evaluation and supply chain risk mitigation. This integrated framework enables decision-makers to identify performance weaknesses, prioritize critical risks, and develop practical mitigation strategies to improve the resilience and sustainability of the MBG supply chain, particularly in geographically dispersed public service environments. Figure 3 illustrates the overall research framework adopted in this study

Fig. 3. Integrated research framework combining SCOR Digital Standard (SCOR-DS) and House of Risk (HOR) for evaluating supply chain performance and risk mitigation in the MBG programme.

4 Results and Discussion

4.1 Supply Chain Mapping Using the SCOR Digital Standard

The first stage of the proposed framework involved mapping the MBG supply chain using the Supply Chain Operations Reference Digital Standard (SCOR-DS). This process mapping establishes the operational boundaries of the study and provides the foundation for subsequent performance evaluation and supply chain risk analysis. Figure 3 illustrates the end-to-end supply chain of the MBG programme, while Table 1 summarizes the corresponding SCOR-DS Level 2 and Level 3 activities associated with each operational process.

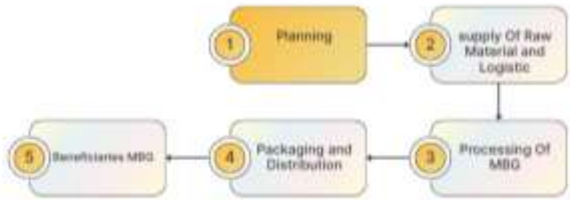

Fig. 4. Supply Chain MBG

The mapping confirms that the MBG supply chain consists of seven interconnected SCOR-DS processes: Orchestrate, Plan, Order, Source, Transform, Fulfil, and Return. Each process involves different stakeholders, ranging from programme managers and food suppliers to logistics providers, catering facilities, schools, and programme beneficiaries. This structured representation demonstrates the complexity of the MBG supply chain, particularly in Indonesia's geographically dispersed 3T regions, where coordination among multiple stakeholders is essential to ensure reliable food distribution. Among the seven SCOR-DS processes, the Source, Transform, and Fulfil processes were identified as the most critical operational stages. The Source process governs procurement planning and supplier coordination, the Transform process covers meal preparation and quality assurance, while the Fulfil process is responsible for transportation and final delivery to schools. Failures occurring within these three processes directly affect food quality, delivery reliability, and programme continuity. Consequently, these processes became the primary focus of the subsequent performance measurement and risk analysis. The SCOR-DS mapping also facilitated the selection of relevant performance indicators for evaluating the operational effectiveness of the MBG supply chain. Based on the mapped processes, Level 1 SCOR-DS metrics, including Perfect Order Fulfilment (POF), Order Fulfilment Cycle Time (OFCT), and Total Supply Chain Management Cost (TSCMC), were employed to establish the baseline performance prior to conducting supply chain risk analysis using the House of Risk framework.

Table 1. SCOR Digital Standard Performance Metrics Used in the MBG Supply Chain Evaluation

SCOR DS Process	Key Stakeholders	Relevant SCOR DS Level 2 Activity	Example of Typical MBG Activity (Level 3)
O - Orchestrate	Program Management & Catering	O1 - Manage Business Rules	O1.2 - Manage Regulatory Compliance: Ensuring adherence to nutritional standards, halal certification, and food safety regulations.
P - Plan	Program Management (Central & Regional)	P1 - Plan Supply Chain	P1.1 - Establish Supply Chain Strategy: Determining

			menu types, budget allocation, and the number of beneficiaries.
D - Order	Beneficiaries/Schools & Catering	D1 - Process Order	D1.1 - Receive, Validate, and Enter Order: Daily/weekly verification of the exact quantity of meals required at each distribution point.
S - Source	Catering/Community Kitchens	S2 - Procure Stocked Product	S2.1 - Schedule Product Procurement: Establishing the schedule and quantity for procuring raw ingredients (rice, vegetables, protein) from local suppliers.
T - Transform	Catering/Community Kitchens	T1 - Schedule Production	T1.2 - Execute Production: The process of cooking, portioning, and packaging meals according to established hygiene and nutritional standards.
F - Fulfill	Logistics Services & Catering	F1 - Ship Product	F1.2 - Ship Product: Distributing the packaged meals, using cold chain transport (if required), to schools or designated distribution points.
R - Return	Catering & Beneficiaries	R1 - Return Defective Product	R1.1 - Authorize Product Return: Handling and reporting food waste or meal rejections due to quality issues or delays.

To assess the performance of a supply chain, SCOR DS Level 1 metrics are applied. The operational information pertaining to the first six months of implementing the MBG Program in XYZ Regency includes delivery time, food waste, and other operational data as raw data. Although accessing conclusive historical data was challenging, the final metric values presented in Table 1, based on semi-structured interviews, received confirmation of accuracy from the following three relevant subject matter experts: Head of the Logistics Distribution Division, Central Catering Manager, and District-level Program Monitoring Staff. These responses illustrate the baseline performance of the MBG supply chain prior to the implementation of strategic approaches to risk identification and mitigation.

4.2 Supply Chain Performance Evaluation.

Following the SCOR-DS process mapping, the operational performance of the MBG supply chain was evaluated using Level 1 SCOR-DS performance metrics. This evaluation provides a quantitative baseline for assessing the effectiveness of the programme prior to conducting detailed supply chain risk analysis. Three key performance indicators were selected to represent the principal dimensions of supply chain performance, namely Perfect Order Fulfilment (POF) for reliability, Order Fulfilment Cycle Time (OFCT) for responsiveness, and Total Supply Chain Management Cost (TSCMC) for cost efficiency. The evaluation results are presented in Table 2.

Table 2. Identified Supply Chain Risk Events in Indonesia's Free Nutritious Meal Programme

Performance Attributes	Metric SCOR DS	Initial Results	Category
Reliability (RL)	Perfect Order Fulfillment (RL.1.1)	75.4%	AVERAGE
Responsiveness (RS)	Order Fulfillment Cycle Time (RS.1.1)	11.5 Jam (Average)	GOOD
Cost (CO)	Total Supply Chain Management Costs (CO.1.1)	Rp 15.500/meal	AVERAGE

Preliminary performance analysis data depicted in Table 1 reveal that the supply chain of the MBG Program in the 3T region is in a "Average" state when it comes to the dimensions of Reliability and Cost. This finding does give sufficient justification for the advancement at the HOR phase, indicating that the program is exposed to considerable operational risk.

- The MBG programme achieved a Perfect Order Fulfilment (POF) score of 75.4%, indicating that approximately one-quarter of procurement and delivery activities failed to satisfy predefined operational requirements. These failures were primarily associated with delayed deliveries, incomplete order fulfilment, and deterioration of food quality during transportation.

Considering that the programme distributes perishable food products to geographically dispersed islands, this level of reliability indicates considerable operational vulnerability. Consequently, improving supply chain reliability should become the primary objective of subsequent risk mitigation activities.

- The average Order Fulfilment Cycle Time (OFCT) was 11.5 hours, which remains within the programme's operational target. Nevertheless, the relatively satisfactory delivery speed contrasts with the moderate POF value, indicating that faster deliveries do not necessarily guarantee reliable service performance. This discrepancy suggests that operational challenges are more closely related to delivery consistency and product quality than to transportation speed alone.

- The Total Supply Chain Management Cost (TSCMC) averaged IDR 15,500 per meal. Although this cost level remains acceptable for public food distribution programmes, the relatively low POF indicates that a proportion of operational expenditure does not generate successful deliveries. In practical terms, delivery failures, food spoilage, and unsuccessful distribution activities increase the effective cost of each meal delivered to beneficiaries. Consequently, improving supply chain reliability is expected to simultaneously reduce operational waste and enhance cost efficiency..

Overall, the SCOR-DS evaluation reveals that the MBG supply chain demonstrates moderate operational performance. While responsiveness remains relatively satisfactory, weaknesses in reliability substantially reduce overall supply chain effectiveness. The coexistence of acceptable delivery speed and moderate fulfilment reliability indicates that operational problems originate primarily from supply chain disruptions rather than process duration. Therefore, performance measurement alone is insufficient to identify the underlying causes of operational failure, highlighting the necessity of a structured supply chain risk assessment using the House of Risk framework. Based on these findings, further investigation was conducted to determine the operational factors responsible for the observed performance deficiencies. Accordingly, the House of Risk (HOR) methodology was employed to identify critical risk events, determine the dominant risk agents, and establish priority mitigation strategies capable of improving the reliability of the MBG supply chain.

4.3 Risk Identification and Prioritization Using House of Risk Phase I

The SCOR-DS performance evaluation presented in the previous section identified reliability as the most critical performance weakness within the MBG supply chain. However, performance indicators alone cannot explain the underlying operational factors responsible for these deficiencies. Therefore, House of Risk (HOR) Phase I was employed to systematically identify risk events, determine their root causes (risk agents), and prioritize the most critical operational risks requiring mitigation. The HOR Phase I analysis was developed by integrating the SCOR-DS Level 3 process mapping with expert judgement. This integration ensures that each identified risk event is directly associated with a specific operational activity, thereby strengthening the traceability between supply chain performance deficiencies and their underlying causes. The analytical procedure adopted in this study is illustrated in

Fig 5. House of Risk (HOR) Phase I Analysis Framework

Based on the analytical framework illustrated in Figure 5, risk identification was conducted by integrating the SCOR-DS Level 3 process mapping with expert judgement. Risk events (Si) were first identified at each supply chain process, followed by the determination of the corresponding risk agents (Aj) responsible for triggering these events. The identified risks subsequently formed the basis for calculating the Aggregate Risk Priority (ARP), enabling the prioritization of risk mitigation efforts.

4.3.1 Identification of Risk Events and Risk Agents

Risk identification was conducted by examining each SCOR-DS Level 3 activity and identifying potential operational failures that could negatively affect the reliability, responsiveness, and cost performance of the MBG supply chain. Risk events (Si) represent undesirable operational outcomes occurring throughout the supply chain, whereas risk agents (Aj) denote the underlying causes responsible for triggering these events. The identification process was carried out through expert judgement involving stakeholders representing procurement, logistics, programme management, and government agencies.

Table 3. Identification of Risk Events and Risk Agents with SCOR DS Level 3 Codes

No.	SCOR DS Level 3 Process	Risk Event (Si) (POF Failure)	POF Attribute	Risk Agent (Aj) (Critical Root Cause in	Dummy Score Si (Severity) (1-10)	Dummy Score Oj (Occurrence) (1-10)

				XYZ 3T Region)		
1	S2.1: Schedule Product Procurement	S1: Delay/Failure in Critical Raw Material Supply (Failure in Timeliness)	Reliability	A1: 90% dependency on external supply (Batam/Java) and complex permitting	9	8
2	S2.4: Authorize Supplier Payment	S2: Unforeseen Rise in Raw Material Prices (Failure in Cost)	Cost (TSCMC)	A2: Fluctuation in ship cargo/fuel tariffs and limited local storage capacity	8	7
3	T1.3: Maintain and Test Product	S3: Food Spoiled or Quality Degradation Due to Distribution Waiting Time (Failure in Quality)	Reliability	A3: Lack of adequate cold chain infrastructure at the catering kitchen and transit points	10	9
4	T1.2: Execute Production	S4: Portion Errors or Menu Nutritional Inconsistency (Failure in Quantity/Quality)	Reliability	A4: Low capacity and unstandardized skills of local caterers/cooks	7	6
5	F1.2: Ship Product	S5: Extreme Delays in Delivery to Remote Island Distribution Points (Failure in Timeliness)	Reliability	A5: Limited sea transport fleet availability and unpredictable extreme weather	9	9
6	F1.4: Pick Product	S6: Damage to Food Packaging during Inter-Island Transport (Failure in Quality)	Reliability	A6: Lack of strict SOPs for handling and specialized packaging for sensitive goods	6	7
7	R1.3: Request Return Authorization	S7: High Level of Food Waste at Distribution Points (Failure in Quality/Cost)	Reliability/Cost	A7: Slow or ineffective feedback process (R1.3) from schools to the caterer	5	5

The identified risk events indicate that the majority of operational disruptions occur within the Source, Transform, and Fulfil processes of the MBG supply chain. These processes are closely associated with procurement reliability, food preparation quality, and transportation performance, which directly influence the overall reliability of meal delivery. Among the identified risk agents, inadequate cold-chain infrastructure (A3), dependence on external suppliers (A1), and maritime transportation disruptions (A5) exhibit the highest combinations of severity and occurrence. These findings demonstrate that logistical infrastructure and geographical constraints constitute the dominant sources of operational uncertainty in Indonesia's outer island food distribution system.

4.3.2 Aggregate Risk Priority (ARP)

Following the identification of risk events and risk agents, the Aggregate Risk Priority (ARP) was calculated to determine the relative importance of each risk agent. The ARP combines the occurrence of each risk agent with the severity of the associated risk events and the strength of their causal relationships. Consequently, higher ARP values indicate risk agents that contribute more substantially to overall supply chain disruption and therefore require higher priority in mitigation planning.

The ARP calculation for each Risk Agent (Aj) is formulated as follows:

$$ARP_j = O_j \text{ x } \sum_{i=1}^{n}(D_{ij}\ X\ S_i)$$

ARP = Aggregate Risk Priority value for the -th Risk Agent.

O_j = Occurrence Score (Probability) of the -th Risk Agent.

Si = Severity Score (Impact) of the -th Risk Event

Dij = Degree of Causality (Cause-and-effect relationship) between Risk Agent and Risk Event .

Table 4 Calculation ARP

Risk Agents (Aj)	Oj (Occurrence)	S1:Critical Supply Delay (9)	S2: Price Increase (8)	S3:Food Spoilage/Degradation (10)	S4:Portion Error (7)	S5:Extreme Delivery Delay (9)	S6: Packaging Damage (6)	S7: High Food Waste (5)	∑(Dij ×Si)	ARP
A1:90% External Supply Dependency	8	9	9	1	0	3	0	0	190	1520
A2:Tariff Fluctuation/Limited Storage	7	3	9	0	0	1	0	0	108	756
A3:Lack of Adequate Cold Chain	9	0	0	9	3	0	9	3	180	1620
A4:Low Cook/Caterer Skills	6	0	0	3	9	0	0	9	138	828
A5:Limited SeaTransport/Extreme Weather	9	3	0	0	0	9	3	0	126	1134
A6:Lack of Packaging SOP	7	0	0	3	0	0	9	1	89	623
A7:Slow Feedback Process	5	0	0	0	1	0	0	9	52	260
		Si Score	Si Score	Si Score	Si Score	Si Score	Si Score	Si Score		
		9	8	10	7	9	6	5		

The ARP results reveal a clear concentration of operational risk within three dominant risk agents. Inadequate cold-chain infrastructure (A3) achieved the highest ARP value (1620), indicating that maintaining food quality throughout transportation and temporary storage represents the most critical challenge for the MBG programme. Dependence on external suppliers (A1) ranked second (ARP = 1520), reflecting the vulnerability of remote island regions to supply interruptions and procurement delays. Maritime transportation limitations and adverse weather conditions (A5) ranked third (ARP = 1134), highlighting the influence of geographical characteristics on delivery reliability.

Collectively, these three risk agents account for more than 65% of the cumulative operational risk, indicating that targeted interventions addressing procurement resilience, cold-chain capability, and transportation reliability are likely to generate the greatest improvements in overall supply chain performance.The prioritization results obtained from HOR Phase I provide a systematic basis for selecting preventive actions in HOR Phase II. Rather than attempting to mitigate all identified risks simultaneously, the subsequent analysis focuses on developing cost-effective mitigation strategies for the highest-priority risk agents identified through the ARP.

4.4 HOR FASE 2

Following the prioritization of critical risk agents through HOR Phase I, the next step involves determining the most appropriate preventive actions to reduce the likelihood of supply chain disruption. House of Risk (HOR) Phase II was employed to evaluate alternative mitigation strategies by considering both their effectiveness in reducing operational risks and the resources required for implementation. This approach enables decision-makers to prioritize mitigation actions that provide the greatest operational benefit while maintaining implementation feasibility.

↓

Fig 6 HOR Phase II Process

4.4.1 Identification of Preventive Actions

Preventive actions were developed to address the highest-priority risk agents identified in HOR Phase I, namely inadequate cold-chain infrastructure (A3), dependence on external suppliers (A1), and maritime transportation disruptions (A5). The proposed actions were formulated through expert discussions involving programme managers, logistics practitioners, and government representatives to ensure both technical feasibility and operational relevance within Indonesia's 3T regions.

Tabel 5 Prioritized Preventive Actions Based on the Effectiveness-to-Cost Ratio (ETCR)

Priority Risk Agent (Aj)	elevant Preventive Actions (Pk)	Description
3: Absence of Cold Chain	1: Implement standardized insulated containers (thermal boxes) for all shipments to distribution points.	xamining the primary concerns associated with food quality throughout distribution.
	2: Improve pre-cooling procedures and production batching in the catering kitchen.	
1: Reliance on External Supply	3: Establishing enduring ties (long-term contracts) with local/regional suppliers on adjacent islands	Reducing upstream vulnerability and cost fluctuations.
	4: Enhance the emergency stock capacity of non-perishable raw materials (safety stock) in the primary 3T warehouse.	
5: Constraints of the Naval Fleet or Meteorological Conditions	5: Diversification of shipping routes and the implementation of a dual fleet comprising fast vessels and conventional ferries as options.	ddressing Timeliness Challenges Arising from Geographical Factors
	6: Establishment of a Meteorological Early Warning System for logistics scheduling	

The identified preventive actions indicate that different categories of operational risks require different mitigation approaches. Risks associated with food quality primarily require improvements in operational procedures and cold-chain management, whereas procurement-related risks emphasize supplier collaboration and inventory management. Transportation risks, on the other hand, require infrastructure enhancement and adaptive logistics planning to accommodate geographical uncertainty.

4.4.2 ETCR Analysis

Since available resources are limited, not all preventive actions can be implemented simultaneously. Therefore, the Effectiveness-to-Cost Ratio (ETCR) was employed to determine the relative priority of each preventive action by balancing its expected effectiveness against the required implementation cost. Actions with higher ETCR values are considered more attractive because they provide greater operational benefits with lower investment requirements...

Formulation ETCR:

$$ETCR_k = \frac{\sum_{j=1}^{m}(E_{kj}\ xO_j)}{Cost\ Treatment\ _k}$$

Description:

- $ETCR_k$: Effectiveness Value to Cost Ratio for Preventive Action to k
- E_{kj} : Action Effectiveness Score of Pk in reducing Risk Agent Aj (Scale 0-10, assessed by experts).
- Oj: Score Occurrence (Probability) Risk Agent to j (from Table 3).
- Cost Treatment k: Estimated Cost of Implementing Preventive Actions (in millions of Rupiah per month).

Table 6 House of Risk (HOR) Matrix Phase II and ETCR Calculation

Relevant Preventive Actions (Pk)	**Cost Treatment (Juta IDR/Bulan)**	**A3: Cold Chain (O=9)**	**A1: External Supply (O=8)**	**A5: Fleet or Weather (O=9)**	**A4: Low Skill (O=6)**	**A2:Rate Fluctuations (O=7)**	$\sum_{j=1}^{m}(E_{kj}\ xO_j)$	***ETCR***	**Rank**

P1: Implementation of Insulated Containers	12	10	30	0	0	0	114	9.50	4
P2:Improved Pre-cooling Procedures	**5**	**8**	**0**	**0**	**7**	**0**	**114**	**22.80**	**1**
P3: Long-Term Contract Local Supplier	**8**	**0**	**10**	**0**	**0**	**9**	**143**	**17.88**	**2**
P4: Increased Safety Stock	**15**	**3**	**9**	**0**	**0**	**8**	**174**	**11.60**	**3**
P5: Route & Fleet Diversification	25	0	0	10	0	0	90	3.60	6
P6: Implementation of Weather EWS Technology	10	0	0	8	0	0	72	7.20	5

The ETCR analysis demonstrates that improving pre-cooling procedures and production batching (P2) achieved the highest priority due to its high effectiveness in reducing food spoilage while requiring relatively limited financial investment. Establishing long-term partnerships with regional suppliers (P3) ranked second, reflecting the importance of improving procurement resilience through supplier diversification and stronger contractual relationships. Increasing emergency safety stock (P4) ranked third, providing additional protection against supply disruptions despite requiring higher inventory investment.

In contrast, infrastructure-intensive interventions such as insulated container procurement (P1), fleet diversification (P5), and weather early warning systems (P6) obtained lower ETCR values because of their relatively high implementation costs. Although these actions remain operationally beneficial, they may be more appropriate as long-term strategic investments rather than immediate operational priorities.

Table 7 Recommendations for Priority Preventive Actions

Rank	Relevant Preventive Actions (Pk)	Value ETCR	Main Focus
1	P2: Enhanced Pre-cooling Protocols and Production Batching	22.80	Extremely Cost-Effective: Concentrates on resolving A3 (Cold Chain) with minimal investment (SOP/HR), achieving superior overall efficacy (114) at the lowest expense.
2	P3: Developing Long-Term Partnerships with Regional Suppliers	17.88	Enhanced Efficiency: Mitigating A1 (External Supply Dependence) through the preservation of pricing stability and supply accessibility.
3	P4: Augmenting Emergency Inventory Capacity of Non-Perishable Raw Materials	11.60	Double Mitigation: Tackling A1 (External Supply) and A2 (Rate Fluctuations) by establishing a substantial buffer.

From a managerial perspective, the ETCR results suggest that significant improvements in supply chain resilience do not necessarily require large capital investments. Several high-priority mitigation strategies involve procedural improvements, enhanced supplier collaboration, and inventory management practices that can be implemented relatively quickly. This finding is particularly relevant for public-sector food distribution programmes operating under budget constraints, where resource allocation must balance operational effectiveness and financial feasibility. The prioritized mitigation strategies derived from HOR Phase II provide practical recommendations for strengthening the resilience of the MBG supply chain. The following section discusses these findings in relation to previous studies, addresses the research questions, and highlights their theoretical and practical implications.

4.5 Discussion

The empirical findings corroborate the assumption that food security logistics in Indonesia's 3T island regions present a worry for ASEAN's maritime territories. The high POF value of 75.4% and the fact that the structure is quite weak show that the major difficulties are with reliability. This corresponds with supply chain management literature that demonstrates the influence of environmental uncertainty on the efficiency of perishable supply chains

The findings also demonstrate the practical value of integrating SCOR-DS and HOR within a single analytical framework. While SCOR-DS effectively identifies performance deficiencies across supply chain processes, it does not explicitly determine the operational factors responsible for those deficiencies. Conversely, HOR systematically prioritizes the underlying risk agents but does not evaluate their influence on overall supply chain performance. By integrating both approaches, this study establishes a direct link between performance measurement, risk prioritization, and mitigation planning, thereby providing a more comprehensive decision-support framework for public food distribution systems..

The Hours of Restoration (HoR) have explicit risk priorities categorized as per geographical and infrastructural considerations. The most significant risks pertain to the lack of a cold chain (A3) and adverse weather conditions or restricted maritime travel (A5). Therefore, the absence of predictable infrastructure and transit severely impacts food quality and transit times. These findings corroborate the literature which states that flexible supply chain management is critical in the food and horticulture sectors since the costs of inefficiencies can be severe. Risk agent A1 (External Supply Dependency, ARP 1520) describes the systemic weakness on the Upstream Supply side, as substantial external island supply dependencies increase cost and time uncertainty. This situation is common in public programs that operate in remote, border, and peripheral areas. The methodological advancement of the current study is significant. Drawing on the SCOR DS up to Level 3 and the HOR Phase I & II frameworks, this study pioneered the cost-effective prioritization of risk for the public sector program performance mapping.This integration methodically correlates performance failures (POF 75.4%) with the fundamental causes of particular 3T risks (A3, A1, A5).

The findings of this study explicitly address the three research questions formulated in the Introduction. First, RQ1 concerning the evaluation of supply chain performance was answered through the application of the SCOR Digital Standard (SCOR-DS), which successfully identified the reliability dimension as the weakest performance attribute, as reflected by the high Performance Opportunity Factor (POF). Second, RQ2 regarding the identification of critical supply chain risks was addressed through the House of Risk (HOR) Phase I analysis, which identified inadequate cold chain facilities (A3), external supply dependency (A1), and adverse weather and maritime transportation disruptions (A5) as the most critical risk agents. Finally, RQ3 concerning the prioritization of mitigation strategies was addressed through HOR Phase II by ranking preventive actions using the Effectiveness-to-Cost Ratio (ETCR), enabling decision-makers to prioritize the most effective and feasible mitigation strategies. These findings demonstrate that the integrated SCOR-DS–HOR framework provides a systematic decision-support approach that links performance evaluation with proactive supply chain risk mitigation.

The primary drawback is the absence of extensive history data (SME validation is necessary for Level 1 measures). Also, the HOR model's Severity, Occurrence, and Causality (Dij) scores are very much based on the subjective opinion of experts, even though they have been cross-checked with operational data. Another disadvantage is that the focus is on 3T Region, which is a typical of the 3T region. This may make it hard to generalize to all 3T regions, which may have distinct infrastructure problems (for example, land vs. maritime infrastructure).

Further research may involve simulations, using System Dynamics or Agent-Based Modeling, to measure the impact of P2 and P3 preventive actions on improving POF.More research is needed to compare the SCM MBG risk priorities between the 3T Maritime regions (as studied) and the 3T Land/Inland regions to find out what the variations are in mitigation priorities. Creating a more detailed SCOR-DS model to track sustainability measures, like carbon emissions from maritime transport, is in line with Industry 4.0 SCM developments.

4 Conclusion

This study developed and applied an integrated Supply Chain Operations Reference–Digital Standard (SCOR-DS) and House of Risk (HOR) framework to evaluate supply chain performance, identify critical operational risks, and prioritize mitigation strategies for the Free Nutritious Meals (MBG) programme in Indonesia's frontier, outermost, and disadvantaged (3T) regions. The integrated framework successfully linked performance assessment with structured risk analysis, providing a comprehensive decision-support approach for improving the resilience of public food distribution systems operating in geographically dispersed and infrastructure-constrained environments. The SCOR-DS assessment indicated that reliability was the weakest performance attribute within the MBG supply chain, highlighting the need to improve delivery consistency and food quality rather than focusing solely on delivery speed.

The HOR analysis further revealed that inadequate cold-chain infrastructure, dependence on external suppliers, and disruptions in maritime transportation were the dominant operational risks affecting programme performance. The prioritization of preventive actions demonstrated that operational improvements, particularly strengthening food handling procedures and establishing long-term partnerships with regional suppliers, provide the greatest potential for reducing supply chain risks while remaining financially feasible. These findings suggest that strengthening operational processes and inter-organizational collaboration can significantly enhance supply chain resilience in remote island regions.

The principal contribution of this research lies in integrating SCOR-DS Level 3 process mapping with HOR Phase I and Phase II into a unified analytical framework for public food distribution systems. Unlike previous studies that generally applied these approaches separately or primarily within manufacturing environments, the proposed framework establishes a systematic relationship between supply chain performance evaluation, risk prioritization, and mitigation planning. This integration extends the applicability of SCOR-DS and HOR to government-led food assistance programmes and offers a practical methodology for supporting evidence-based decision-making in complex humanitarian and public-sector supply chains. From a managerial perspective, the proposed framework provides government agencies and programme managers with a structured approach for allocating limited resources to the most critical operational improvements.

By prioritizing preventive actions that balance effectiveness and implementation cost, policymakers can improve programme reliability while strengthening food quality assurance and logistics resilience in geographically isolated regions. Future research should validate the proposed framework across multiple 3T regions with different logistical characteristics and integrate dynamic simulation approaches, such as System Dynamics or Agent-Based Modelling, to evaluate the long-term impacts of mitigation strategies under various operational scenarios. Furthermore, incorporating sustainability indicators, including environmental performance and carbon emissions from maritime logistics, would further enhance the framework in supporting resilient and sustainable public food supply chains.

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